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Assessment of technical efficiency for garlic production in Guilan province of Iran

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ABSTRACT

In this study a non–parametric method of data envelopment analysis (DEA) was applied to analyze the energy efficiency and its optimization for garlic producers of Guilan province, Iran. The initial data were collected from 60 farmers using face-to-face questionnaire method in the villages of the Langroud city in the mentioned province. For garlic production processing, there was seven input energy (including human labor, machinery, diesel fuel, chemical fertilizers, seed, biocides and farmyard manure) and one output energy (including garlic yield). For applying DEA method, we use of two methods covering CCR and BCC models. The results of these models indicated that 18 and 43 units was efficient as technical and pure technical efficiency, respectively. Also, the scale efficiency score of 18 units was one in the studied area. The average of technical, pure technical and scale efficiency scores was computed as 0.847, 0.940 and 0.896, respectively. Moreover, the total energy use can be reduced about 6552 MJ ha^{-1} comparing present condition (with 17.81% difference). The highest difference between optimum and present condition was found in diesel fuel and seed with 19.88% for both of them. The chemical fertilizers (with 46.83%) and diesel fuel (with 17.98%) had the highest share of total energy saving in garlic production by DEA approach, respectively.

Introduction

Garlic (*Allium sativum*) is classified under the Alliaceae family and is widely consumed for its culinary and medicinal benefits. Garlic is a relatively good source of calcium, phosphorus, and potassium. Its leaves are sources of protein and of vitamins A and C. Garlic is said to contain antibiotic substances that inhibit the growth of certain bacteria and fungi. Garlic can be grown in different types of soil. Garlic is planted by hand in the fall and harvested in the following summer (Samavatean et al., 2011). Energy is one of the most important indicators of crop performance. The net energy and monetary return of a cropping system can be quantified for sound planning of sustainable systems. Yield and economical parameters increased linearly as level of fertility increased, while the reverse trend is observed with energy-use efficiency, energy productivity and energy intensiveness. The share of agriculture in national energy consumption was rising consistently over the last three decades. Presently, it accounts for nearly a quarter of the country’s electric consumption. Yield of different crop can be increased up to 30% by using an optimal level of energy input (Singh et al., 2008). Energy use in agriculture has developed in response to increasing populations, limited supply of arable land and desire for an increasing standard of living. In all societies, these factors have encouraged an increase in energy inputs to maximize yields, minimize labor-intensive practices, or both (Esengun et al., 2007). Data envelopment analysis (DEA) analyses the efficiency of a production unit in using and combining inputs to produce a given level of output. DEA has been usually applied to decision-making units such as firms to detect inefficiencies and reduce them by adjusting the use of inputs. The efficiency of units of production, such as logs, can be analyzed by the efficiency frontier approach which includes two methods, DEA which is a non-parametric deterministic model, and the stochastic frontier which is a parametric production function (Alzamora and Apiolaza, 2014). Here DEA is used for the estimation of resource use efficiency and ranking of farms or production units on the basis of their performances. The present study explores DEA technique which permits efficiency estimation of watermelon farms without assuming an a priori functional form for frontier production (Banaeian and Namdari, 2011). In recent years, many authors applied the DEA approach for optimization of energy consumption in agricultural and horticultural crops. Chauhan et al. (2006) studied the possibility of improving energy productivity in paddy production through benchmarking. In their study, a DEA approach was used to determine the efficiencies of farmers with regard to energy use in rice production activities in the alluvial zone in the state of West Bengal in India. Samavatean et al. (2010) examined the DEA approach to the improvement of energy consumption in garlic production of Hamedan province, Iran. In another study, the technical efficiency was examined for canola production by Mousavi-Avval et al. (2011). Moreover, Mousavi-Avval et al. (2012) surveyed the efficiency indices of DEA of barberry production in the north of Iran. Mobtaker et al. (2012) applied the DEA method for determination of technical efficiency in alfalfa production in Hamedan province of Iran. Nabavi-Pelesaraei et al. (2014a) investigated the energy optimization for rice production using DEA approach.

Mohammadi el al. (2013) joined the DEA and life cycle assessment for optimization of energy use and environmental impacts in soybean production.

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With respect to mentioned introduction, the present study offered the energy consumption rate of technical efficiency and optimized pattern for garlic production in Guilan province of Iran from the energy consumption point of view by DEA approach.

Materials and methods

Sampling design

The study was carried out in 60 garlic producer in the Langroud city of Guilan province, Iran. This province is located in the north of Iran, within 36° 34′and 38° 27′ north latitude and 48° 53′ and 50° 34′ east longitude (Nabavi-Pelesaraei et al., 2014b). Data were collected from the growers by using a face-to-face questionnaire performed in March 2013. Farms were randomly chosen from the villages in the area of study. The size of each sample was determined using a simple random sampling method.

This method was described by Kizilaslan (2009):

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \qquad (1)$$

Where n is the required sample size; s is the standard deviation; t is the value at 95% confidence limit (1.96); N is the number of holding in the target population and d is the acceptable error (permissible error 5%). For the calculation of sample size, criteria of 5% deviation from population mean and 95% confidence level were used. The sample size was calculated as 47 but for precision competition 60 units were selected randomly.

Energy equivalents of inputs and output

The energy inputs of garlic production included human labor, machinery, diesel fuel, chemical fertilizers (nitrogen, phosphate and potassium), farmyard manure, biocides and seed; while the only energy output was garlic yield in this research. Table 1 showed the energy equivalent with the physical amount of inputs for garlic production per hectare. The energy consumption of each input was calculated by multiplying energy standard coefficient with the amount of inputs which showed in Table 1. As can be seen in the last column of Table 1, the total energy use and yield of garlic production was found about 36617 MJ ha^{-1} and 14637 kg ha^{-1}, respectively. *2.3. Data envelopment analysis (DEA)*

DEA, after the work of Farrell (1957), has been a well-established methodology to evaluate the relative efficiencies of a set of comparable entities or production units using some specific mathematical programming models. Production units are called decision-making units (DMUs) in DEA terminology. Based on the above mentioned explanation, the DEA is used to determine the efficiency of DMUs relative to others in the group and to evaluate inefficient units. This technique can also be used to identify the level as well as sources of inefficiency. Here, DEA is used for the estimation of resource use efficiency and ranking of garlic producers or production units on the basis of their performances.

DEA has two models including CCR and BCC models. The CCR DEA model developed by Charnes et al. (1978) and 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 (2007). On the other hand the BCC DEA model developed by Banker et al. (1984) and assumes variable returns to scale conditions. It decomposes the technical efficiency into pure technical efficiency for management factors and scale efficiency for scale factors. Thus, pure technical efficiency is the technical efficiency that has the effect of scale efficiency removed (Mousavi-Avval et al., 2011).

Technical efficiency (TE)

TE can be defined as the ability of a DMU to produce maximum output given a set of inputs and technology level. The TE score in the presence of multiple input and output factors can be calculated as follows (Mousavi-Avval et al., 2011):

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

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 the number of outputs ($r = 1, 2 \ldots n$); s is the number of inputs ($s = 1, 2 \ldots m$) and j represents j^{th} of DMUs ($j = 1, 2 \ldots k$).

To solve Eq. (2), following Linear Programming (LP) was formulated:

Maximize

$$\theta = \sum_{r=1}^{n} u_r y_{rj}$$

Subjected to

$$\sum_{r=1}^{n} u_r y_{rj} - \sum_{s=1}^{m} v_s x_{sj} \le 0 \qquad (3)$$

$$\sum_{s=1}^{m} v_s x_{sj} = 1$$

$$u_r \ge 0,\ v_s \ge 0, \quad \text{and (i and j= 1, 2, 3, ..., k)}$$

Where θ is the technical efficiency, Model (3) is known as the input oriented CCR DEA model assumes constant returns to scale (CRS) (Avkiran, 2001).

Pure technical efficiency

The Pure Technical Efficiency (PTE) measures how a DMU utilizes the resources under exogenous environments; a low PTE implies that the DMU inefficiently manages its resources. In another word, PTE is the technical efficiency of BCC model. On the other hand BCC model decomposes the technical efficiency into pure technical efficiency for management factors and scale efficiency for scale factors. Thus, pure technical efficiency is the technical efficiency that has the effect of scale efficiency removed (Nabavi-Pelesaraei et al., 2014a).

Mobtaker et al. (2012) expressed it by Dual Linear Program (DLP) as follows:

Maximize $z = uy_i - u_i$

Subjected to $vx_i = 1$ (4)

$-vX + uY - u_o e \le 0$

$v \ge 0,\ u \ge 0$ *and* u_o *free in sing*

Where z and u_0 are scalar and free to sign; u and v are output and input weight matrixes, and Y and X are the corresponding output and input matrixes, respectively. The letters x_i and y_i refer to the inputs and output of its DMU.

Scale efficiency

The convexity constraint ensures that an inefficient farm is only “benchmarked” against farms of a similar size. This convexity restriction is not imposed in the CRS case. Hence, in a CRS DEA, a farm may be benchmarked against farms that are substantially bigger or smaller than it. This introduces scale efficiency, which measures the effect of DMU size on the efficiency of the system, i.e. It is the potential productivity gain from achieving optimal size of a DMU. Scale efficiency indicates that some part of inefficiency could be attributed to the inappropriate size of DMU. The following relationship is used to obtain scale efficiency score of the kth DMU (Khoshroo et al., 2013).

The scale efficiency formula followed described by Khoshroo et al. (2013):

$$Scale\ efficiency = \frac{Technical\ efficiency}{Pure\ technical\ efficiency} \qquad (4)$$

Basic information on energy inputs of garlic production were entered into Excel 2013 spreadsheets, and Efficiency Measurement System (EMS) software programs.

Results and Discussion

Efficiency estimation of farmers

Initially we applied the CCR model to evaluate the technical or overall efficiencies of all DMUs. Additionally, we used the BCC model to evaluate the pure technical efficiency and scale efficiency. The results of the CCR and BCC models are shown in Fig. 1 and Table 2. Based on CCR results, this study shows that only 18 growers were relatively efficient and the remaining 42 were inefficient, i.e., their efficiency scores are below 1; while from the results of BCC model, 43 growers (out of total 60 growers) were found as efficient garlic producers, meaning they have an efficiency score of 1. The scale efficiency was calculated as 1 for 18 farms. In other word the all efficient units of the CCR model were efficient in BCC model.

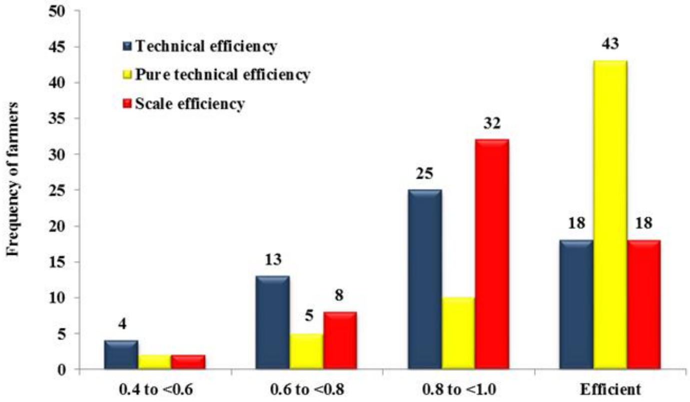

Fig 1. Efficiency scores distribution of garlic producers

Samavatean et al. (2010) reported the 38.29% of total garlic producers were efficient based on CCR model in Hamedan province of Iran. Also, their results indicated that the BCC model found 55.31% of total units as efficient.

Ac can be seen in Table 2, the average of three estimated measures of efficiency is demonstrated with values of standard deviation, minimum and maximum of scores for garlic producer in Guilan province of Iran. Based on results, the average of technical, pure technical and scale efficiency was calculated as 0.847, 0.940 and 0.896, respectively. Also, the standard deviation of technical efficiency had the highest rate between all indices. Moreover, 0.330, 0.503 and 0.340 was as the minimum value of technical, pure technical and scale efficiency, respectively. *3.4. Optimum energy requirement and saving energy*

The optimum energy requirement and energy saving of various farm inputs for garlic production based on the results of the BCC model are given in Table 3. The results revealed that the total energy requirement in optimum condition for garlic production was 30094.75 MJ ha^{-1}; so, about 6552 MJ ha^{-1} can be reduced in garlic production process form an energy point of view. In other words, the 17.81% of total energy use in present farms can be saved in DEA approach pattern. Energy estimated of diesel fuel and seed in optimum (with 19.88% for both of them) had the highest percentages of saving energy comparison present condition; followed by chemical fertilizers (18.45%) and machinery (17.53%).

Fig. 2 shows the distribution of different sources in the total input energy saving. Results revealed that the highest contribution to the total energy saving is from chemical fertilizers (46.83%) followed by diesel fuel (17.98%) and seed (15.84%). The greatest scope for energy saving of chemical fertilizers and diesel fuel indicates that farmer's knowledge of proper timing and amount of water for using of chemical inputs (especially nitrogen) and applying standard machinery in garlic production was very low. They believed the more consumption of each input can be increased garlic production, significantly. The low prices of chemical inputs and lack supervision of the energy use pattern were the main reasons of this problem in the studied region.

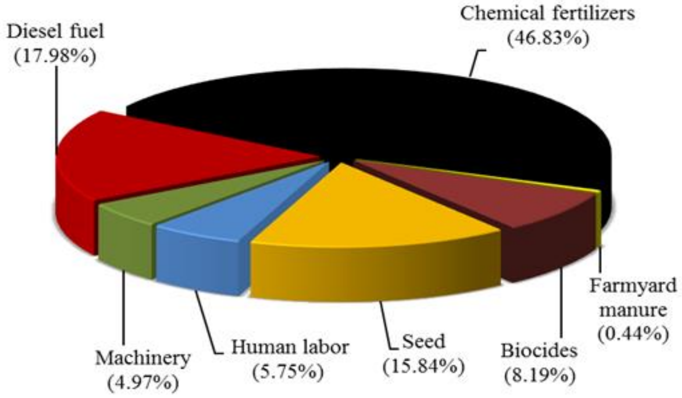

Fig 2. The contribution to the total savings energy for garlic production

Samavatean et al. (2010) reported the similar results for share of each input in total energy saving for garlic production in Hamedan province of Iran. Based on their results, the highest share of total energy saving was belonged to chemical fertilizers (about 14%); followed by diesel fuel (about 12%).

Conclusions

In this study, the non-parametric method of DEA was applied to analyze the efficiencies of garlic producers in Guilan province of Iran. Data were collected from 60 garlic producers of the Langroud city by a face to face questionnaire method. After data collection, the variety of efficiency was determined by CCR and BCC models of DEA approach.

The following results were concluded from this study:

1. The results of the CCR and BCC model indicated that 18 and 43 garlic producers were efficient in technical and pure technical efficiency, respectively. Moreover, the numbers of units with score one was 18 for scale efficiency.
2. With respect to the results, the average of three estimated measures of efficiency, including technical, pure technical and scale efficiency scores was calculated as 0.847 (with standard deviation 0.168), 0.940 (with standard deviation 0.117) and 0.896 (with standard deviation 0.121), respectively.
3. The results of energy saving showed the total energy use can be reduced about 6552 MJ ha^{-1} comparing present condition (with 17.81% difference). Furthermore, diesel fuel and seed had the highest difference in optimum condition comparing present farms with 19.88% for both of them.
4. The highest share of total energy saving belonged to chemical fertilizers (with 46.83%) and diesel fuel (with 17.98%), respectively.

Table 1. Energy coefficients and energy inputs/output in various operations of garlic production

Items (unit)	Energy equivalent (MJ unit^{-1})	Quantity per unit area (ha)	Total energy equivalent (MJ ha^{-1})
A. Inputs			
1. Human labor (h)	1.96 (Mobtaker et al., 2012)	1853.76	3633.378
2. Machinery (h)	62.7 (Rafiee et al., 2010)	29.49	1849.08
3. Diesel fuel (l)	56.3 (Barber, 2003)	104.74	5897.89
4. Chemical fertilizer (kg)			
(a) Nitrogen	66.14 (Mousavi-Avval et al., 2011)	209.56	13860.03
(b) Phosphate (P_2O_5)	12.44 (Unakitan et al., 2010)	42.08	523.5333
(c) Potassium (K_2O)	11.15 (Pahlavan et al., 2011)	194.91	2173.276
5. Farmyard manure (kg)	0.3 (Nabavi-Pelesaraei et al., 2014b)	1040.71	312.213
6. Biocides (kg)	120 (Nabavi-Pelesaraei et al., 2013)	26.43	3171.349
7. Seed (kg)	1.6 (Samavatean et al., 2011)	3247.52	5196.038
The total energy input (MJ)			36616.78
B. Output			
1. Garlic (kg)	1.6 (Samavatean et al., 2011)	14636.53	23418.45
Total energy output (MJ)			23418.45

Table 2. Average technical, pure and scale efficiency of garlic farmers.

Particular	Average	SD	Min	Max
Technical efficiency	0.847	0.168	0.330	1.000
Pure technical efficiency	0.940	0.117	0.503	1.000
Scale efficiency	0.896	0.121	0.433	1.000

Table 3. Optimum energy requirement and saving energy for garlic production.

Inputs	Optimum energy requirement (MJ ha^{-1})	Saving energy (MJ ha^{-1})	Saving energy (%)
1. Human labor	3258.21	375.16	10.33
2. Machinery	1524.90	324.17	17.53
3. Diesel fuel	4725.35	1172.54	19.88
4. Chemical fertilizers	13502.86	3053.98	18.45
5. Farmyard manure	283.47	28.74	9.21
6. Biocides	2636.92	534.42	16.85
7. Seed	4163.03	1033.01	19.88
Total energy	30094.75	6522.03	17.81

5. The results illustrated there are irregular consumption of chemicals, diesel fuel and seeds in the agricultural systems of garlic production in Guilan province of Iran. So, it's suggested the use of chemical fertilizer, diesel fuel and seed should be close to optimum condition which introduced in this study for studied area. For this purpose, supervision of fertilizer consumption by local experts and applying standard machinery with timely maintenance can be helped to the improvement of energy issues in garlic production of Guilan province, Iran.

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